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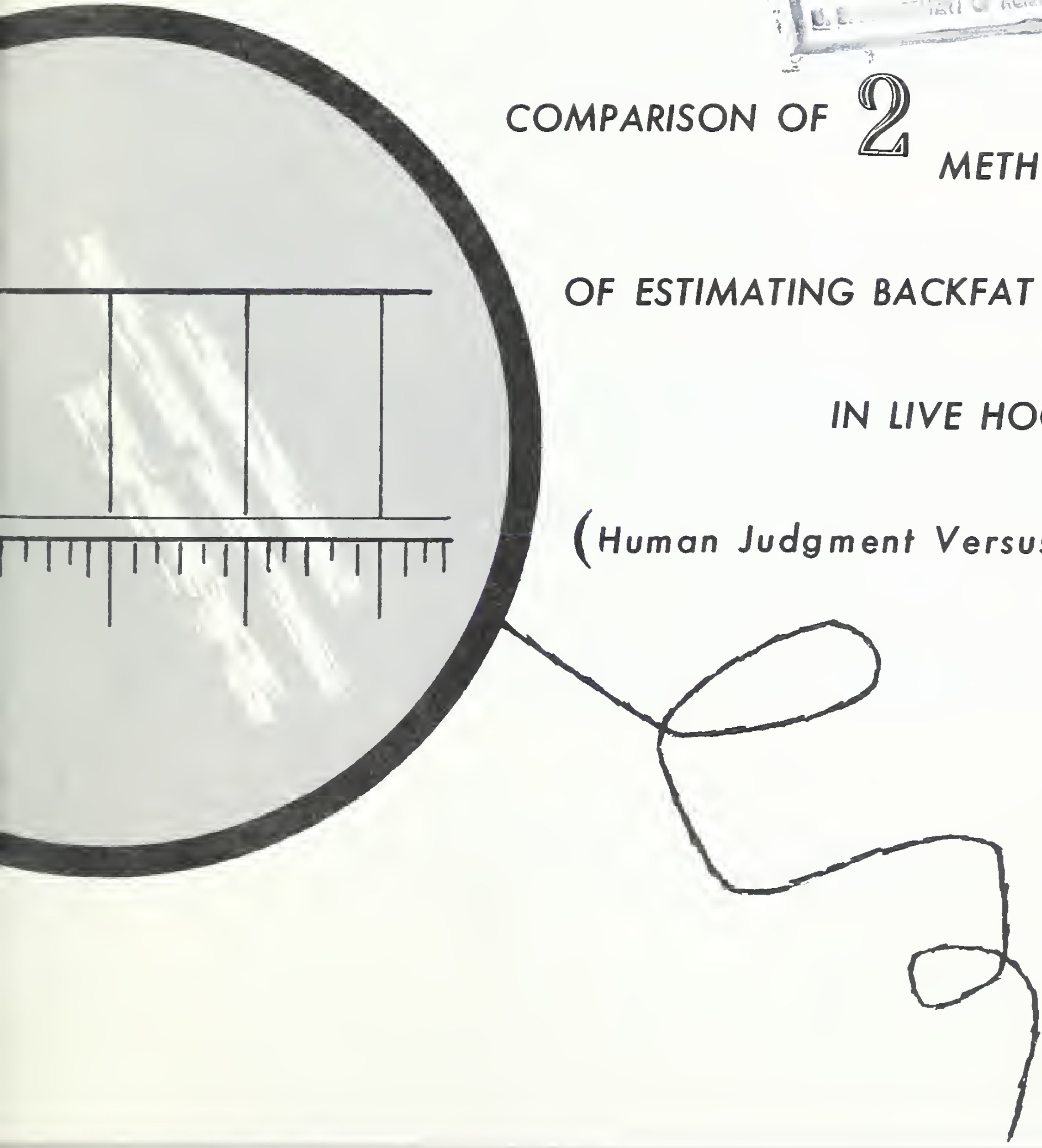
COMPARISON OF 2 METHODS OF ESTIMATING BACKFAT THICKNESS IN LIVE HOGS

(Human Judgment Versus Ultrasonics)



A Preliminary Report
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U. S. DEPARTMENT OF AGRICULTURE
Agricultural Marketing Service
Marketing Research Division

PREFACE

Farmers, packers, and consumers could profit from a more accurate appraisal of live hog values. Backfat thickness is an important indicator of the value of a hog. However, official standards take estimates rather than actual backfat measurements into consideration in live hog grading.

The basic data of this report are measurements of backfat thickness of 170 live hogs obtained by an ultrasonic device and estimates of backfat thickness by an experienced grader. These measurements and estimates are compared with the actual measurements of backfat thickness of the carcasses of the same hogs after slaughter.

ACKNOWLEDGMENTS

The Curtiss-Wright Corporation, Princeton, N. J., provided an ultrasonic device and an operator. The Livestock Division of the Agricultural Marketing Service provided a grader.

Representatives of the Animal Husbandry and Agricultural Engineering Research Divisions of the Agricultural Research Service, the Livestock Division of the Agricultural Marketing Service, and of the Farmer Cooperative Service of the U. S. Department of Agriculture, and of the Division of Markets, Virginia Department of Agriculture, assisted in the gathering of the data. Kenneth J. McCallister of the Agricultural Marketing Service suggested the method used for illustrating the effect of a given increase in grading accuracy on the grade-price differentials that can be paid.

The Shen-Valley Packers, Inc., Timberville, Va., kindly permitted hogs in their plant to be evaluated by the two methods and permitted the carcasses to be measured after slaughter.

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June 1959

SUMMARY AND CONCLUSIONS

On 170 live hogs, backfat thickness measurements made with an ultrasonic device were better estimates of the backfat thickness of the butchered carcasses, as measured with a ruler, than were live estimates by an experienced hog grader.

The accuracy of live hog grading is determined to a considerable extent by the accuracy with which backfat thickness is estimated. Although use of the ultrasonic device could lead to improved live hog grading accuracy, a number of problems are connected with the use of the machine. It may be too slow for commercial use in grading live hogs for slaughter. Even under ideal conditions, each hog would have to be stopped near the machine, while an experienced grader can sort several hogs per minute by "eye." Another factor to consider in evaluating the possible commercial use of the machine is the possibility that grading may increasingly be done after slaughter rather than before, and the usefulness of the ultrasonic device on carcasses has not been demonstrated. Furthermore, the machine may appear to be costly to potential users, and a standby machine might be needed in case of breakdown. Additional research may aid in the solution of some or all of the problems mentioned above.

More information is needed on the relationship between ultrasonic estimates of backfat thickness, and value of the wholesale cuts from a carcass. In this study, the relationship between live ultrasonic measurements and carcass backfat thickness was studied, but wholesale cut yields were not obtained.

Only one grader was used in the study. The results might have been different if other graders had been used. However, the grader was highly experienced and considered to be above average in ability. Workers at various Agricultural Experiment Stations and USDA workers at Beltsville, Md., will announce results of further studies of the accuracy of the ultrasonic method.

In addition to presenting the results of the one experiment, this report presents a method of analysis for studying the economic impacts of improvements in grading accuracy. One of the results of an increase in grading accuracy is a widening in value differentials between adjacent grades. Wider value differences permit wider price differentials to be paid between grades, and wider grade-price differentials provide additional incentive for production of higher quality hogs. The analysis indicated the possibility of a 25 percent increase in value differentials between grades if hogs were graded by the backfat estimates having the accuracy of the ultrasonic device rather than by backfat estimates of the accuracy of the human grader.

Preliminary Report

COMPARISON OF TWO METHODS OF ESTIMATING BACKFAT THICKNESS IN LIVE HOGS

(Human Judgment Versus Ultrasonics)

by Raymond O. Gaarder
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> "Sound too high for human hearing has a peculiar fascination which perhaps explains why so much is expected of it. If its applications are few, they are impressive and promise others." (13) 1/

INTRODUCTION

An important problem of swine production and marketing is to find accurate and economical methods of determining leanness or meatiness in the quality evaluation of breeding swine and in the grading of live slaughter swine.

Given weight or length, backfat thickness has been found to give a good indication of the percentage the major lean cuts are of the live hog or carcass. Measurement of backfat thickness of a hog carcass is simply a matter of placing a ruler at the point on the split carcass where a measurement is desired. However, backfat measurement or estimation on the live hog is still an art which requires considerable skill, and new methods deserve study.

DEVELOPMENT OF METHODS AND TECHNIQUES OF BACKFAT ESTIMATION

Research of the 1940's indicated that the highly correlated relationship between the yield of lean cuts and backfat thickness could provide the basis for grade standards for hogs (7). Other work has shown that backfat thickness is highly heritable and that leaner and faster-growing animals can be produced from breeding stock that has been selected by backfat thickness and weight (17).

The live-probe method of measuring backfat thickness of live hogs was announced in 1952 (11). This method employs a thin metal ruler which is pressed through an incision in the skin and through the underlying fat until it is stopped by a layer of connective tissue adjacent to the lean (fig. 1).

In 1954, the development of the Leanmeter for measuring backfat thickness in live hogs was announced (1). The principle of operation of the Leanmeter is based on the difference in electroconductivity of fat and muscle. The

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1/ Underscored figures in parentheses refer to items in Literature Cited, p.24 .

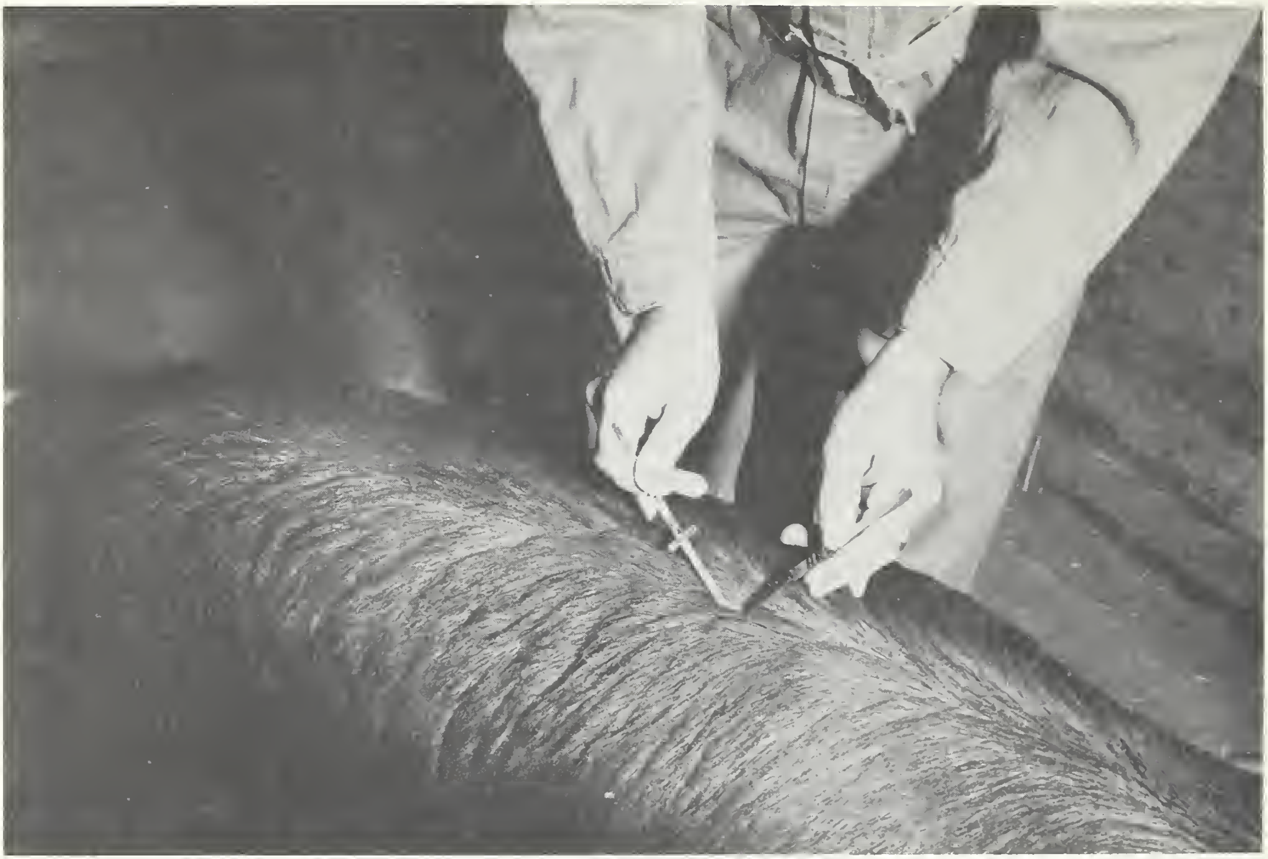

Figure 1 - The Live Probe N 25801

device involves a slender needle containing electrodes which is inserted in the hog's back until the electrodes reach lean tissue. When a dial indicates that the electrodes have reached a tissue of different electroconductivity than the fat through which they have been traveling, the needle is withdrawn (fig. 2). The depth of backfat thickness through which the needle was inserted is thereby indicated.

Both the live-probe method and the Leanmeter are fairly accurate estimators of carcass backfat thickness and of the percentage lean cuts are of the total carcass weight (24). However, the methods are time consuming and require that the animals be made to stand quietly.

An attempt to predict percent of lean cuts from fat and lean thickness as determined by joint use of a regular (ruler) probe and a pick probe was reported in 1958 (15).

European workers have reported on tests of the ultrasonic deviece on hogs and have obtained good estimates of backfat thickness with it (3, 6, 9, 18, 20). The ultrasonic device for backfat thickness determination is an instrument which measures the time time required for a high-frequency sound wave

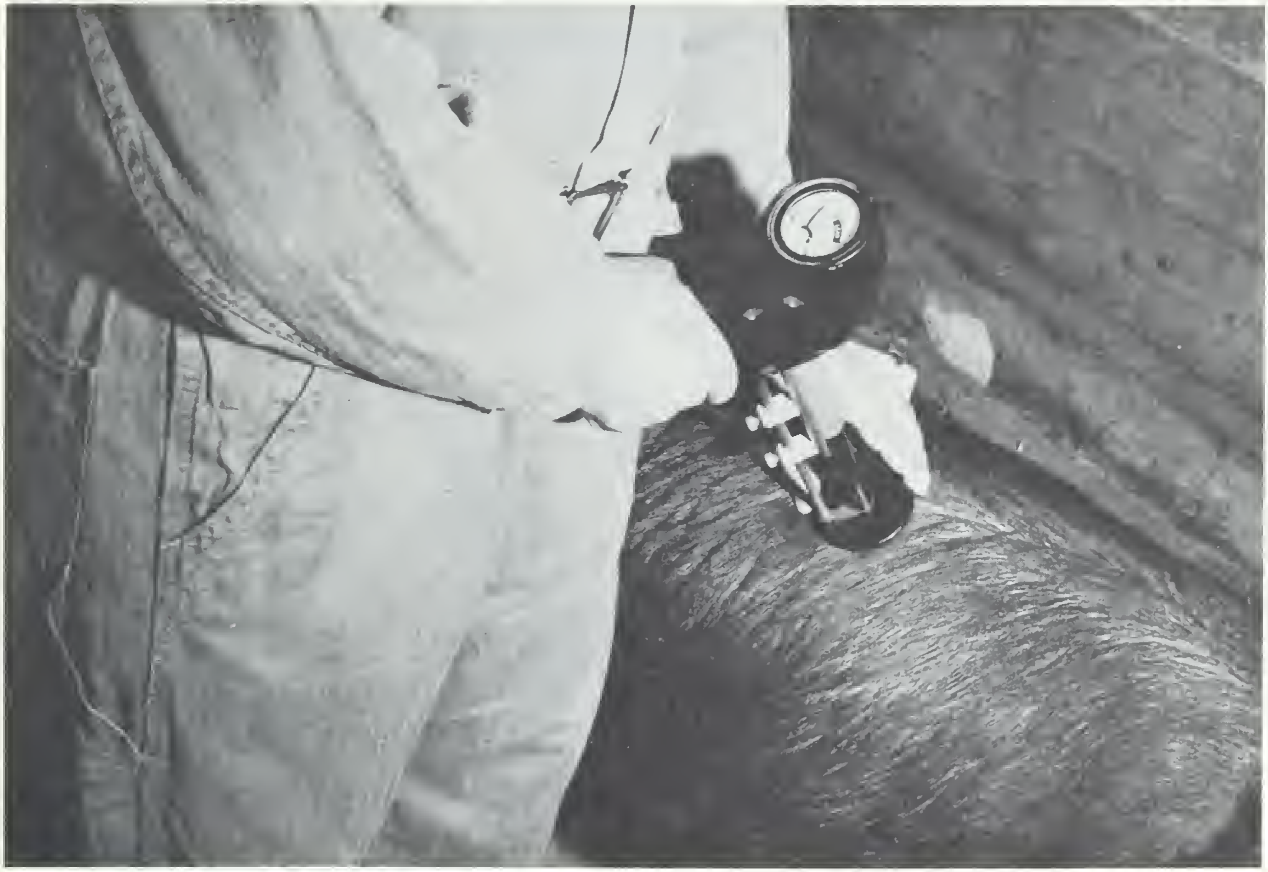

Figure 2 - The Leanmeter N 25800

to travel down from the skin through the backfat to a layer of lean or bone and rebound to the skin. The device translates the time interval into inches of backfat.

Two types of ultrasonic devices have been used in the United States for measuring fat thickness in live cattle (26, 27). One device was designed to measure depth of subcutaneous fat at one point at a time. The other was designed to provide a visulization of subcutaneous fat depth along a line drawn across the animal's back.

The ultrasonic device used in tests described in this report was of the type that measures fat thickness at one point at a time.

PRINCIPLES OF THE ULTRASONIC METHOD

The source of the ultrasonic sound in this experiment was a crystal high-frequency vibrator called a transducer. The transducer is small, and can be held in the palm of the operator's hand (fig. 3). As it is connected to the other parts of the device by an electric cord, it is not difficult to hold it against the back of an animal. In addition, the complete ultrasonic device is portable.

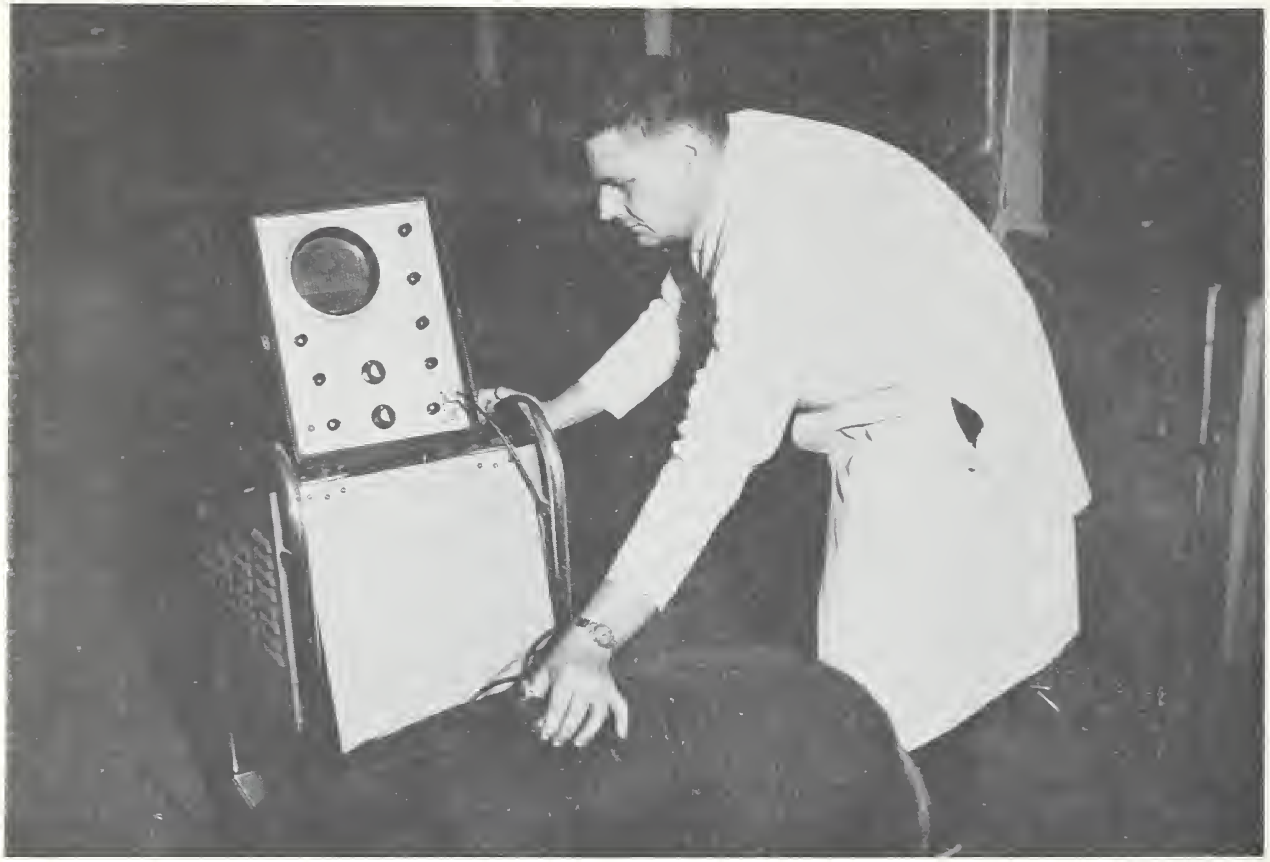

Figure 3 - The Ultrasonic Device N 25802

The transducer can be energized by either electrical or physical energy. When electrical charges are momentarily applied, the crystal vibrates at a high frequency, generating ultrasonic sound waves. Likewise, when such sound waves rebound or come from another source and strike the resting crystal (transducer), high-frequency vibrations occur which, in turn, generate electrical charges.

If the transducer is pressed against a solid or touched to a liquid and electronically turned on for a moment, a number of waves (a pulse) of ultrasonic "sound" will leave the transducer and travel through the adjacent solid or liquid object. When a pulse of sound reaches a material in the object that is of different density than that through which it has been passing, a part of the pulse (an echo) is reflected back toward the transducer. The remaining portion of the sound pulse continues on through the adjacent material. 2/ On its return, a part of the reflected portion of the pulse strikes the resting transducer generating an electric charge. This charge is automatically transmitted to a part of the ultrasonic device called an oscilloscope.

2/ Adjacent areas may differ in density by as much as 10 percent and show insignificant difference on the x-ray. Differences in density as small as 1/1,000 can be discerned with an ultrasonic device (16).

The face of the oscilloscope is similar to that of a television picture tube. When the oscilloscope receives no electrical charges from echoes, a straight horizontal line appears on its face. Each electric charge from an echo striking the transducer causes a pip (notch or jog) to appear in the line. The distance from the origin of the line to a pip is an indication of the distance from the transducer (which is placed against the hog's back) to the interface that returned the echo.

The distance to the pip that would indicate backfat thickness over the backbone depends upon the time interval from the instant a sound pulse leaves the transducer until an echo is returned from the bone. The time interval in turn depends upon the distance to the bone and back to the transducer -- and upon the speed of travel of ultrasonic sound in hog fat.

When a sound wave strikes an interface between two types of soft tissue such as fat and lean, part of the energy continues on its path until it strikes another interface. This process continues until the sound wave is so weak it will not go any further or until it reaches material such as bone that is not a conductor of ultrasonic sound. If the vibrator were held over the loin muscle on a hog's back, partial echoes would be returned by a layer of connective tissue buried in the fat and the interface between the backfat and the loin muscle. 3/ The distance to each interface could then be inferred from the distance to each pip on the oscilloscope. If a sufficiently strong signal could be sent by the vibrator, portions of the sound wave would continue down through the loin muscle and, if aimed properly, returned an echo from a rib lying beneath the muscle. Thus, if the operator is able to interpret the pips, it may eventually be possible to determine both backfat thickness and loin eye muscle thickness.

In the experiment reported in this paper, the vibrator was held over the backbone of the hog. Backfat thickness was measured at three points over the bone, and no attempt was made to measure loin eye muscle thickness. The operator ignored pips that appeared to be returned by interfaces above the backbone. The first major pip usually represented the distance to a layer of connective tissue lying within the fat, and the second the distance to the backbone.

3/ More recent USDA research has been able to eliminate the rather misleading "pip" which comes from the connective tissue layer.

The type of ultrasonic devices or methods discussed so far have been devised for inspection of material. Ultrasonics also has uses in the alteration of the material in which it operates. 4/

USE AND APPLICATION OF ULTRASONICS IN THIS STUDY

The Hogs Used and Measurements Taken

On April 30 and May 1, 1958, live estimates were made of the average backfat thickness of each of the 170 hogs used in this test. The hogs were slaughtered on May 2. To obtain a sufficient number of hogs in each grade, the proportion of U. S. No. 3 hogs selected for the test was higher than the proportion of No. 3 hogs in the holding pens of the plant. Table 1 shows the carcass grade distribution of the hogs used, as determined after slaughter. The basic data of this report are measurements and estimates of backfat thickness of the 170 live hogs (barrows and gilts) obtained (1) by an ultrasonic device and (2) by the judgment of an experienced grader. These measurements and estimates are compared with the actual measurements of backfat thickness of the carcasses of the same hogs after slaughter. Most of the hogs were in the 200-to-220-pound weight range.

The three carcass backfat measurements were taken over the backbone, at the first and last ribs, and last lumbar vertebra. On the live hogs, these points could be described as being over the shoulder, over the middle of the back, and over the ham. The three locations are specified by the U. S. standards for grades of slaughter barrow and gilt carcasses (28).

It has been customary in probing live hogs to use points about 1½ inches off the midline of the back. However, in this experiment, the vibrator was applied on the midline of the live hog because the backfat measurements obtained were to be compared with measurements from carcasses split down the middle.

4/ In measurement or inspection of material, ultrasonic devices for detecting flaws, grain size, thickness, and incipient fatigue in metals have been remarkably successful and had largely replaced x-ray testing in many applications by 1952. The history of the early development of ultrasonics in measurement is traced by Howry and Bliss (16). Other possible applications of ultrasonics in measurement may have possibilities, and some are, no doubt, being investigated. For example, increasing interest in the problem of obesity in humans has led to investigation of the usefulness of x-rays for providing objective measures (10). Ultrasonics could be used without fear of radiation.

Table 1.--Carcass grades of the 170 barrows and gilts measured

Grade	Number	Percent
U. S. No. 1	62	36
U. S. No. 2	58	34
U. S. No. 3	41	24
Medium	8	5
Cull	1	1
Total	170	100

Application of the Vibrator to the Hog

In order that the ultrasonic readings could be obtained, the hogs were restrained by penning them one at a time in a double-gated crate. When an animal was trapped in the crate, motor oil was applied to the hair at the three points on the hog's back at which measurements were to be taken. This was necessary because air, held by the dry hair, is not a conductor of ultrasonic sound waves. 5/

In this experiment, one worker was able to perform all the tasks connected with the actual measuring. To make a measurement, he applied the oil with one hand and used the other to place the vibrator in the oil puddle on the hog's back. Then he glanced up at the oscilloscope, read the measurement of backfat thickness, and relayed it to a recorder.

ANALYSIS OF THE DATA

In analyzing the data of this report, it has been assumed that carcass backfat was measured without error. Since the measurement of carcass backfat is made directly with a ruler it is not subject to important errors of judgment. In this study, the variance of the individual differences between one set of average carcass backfat measurements and a replicate set (each

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5/ A continuous application of water between the vibrator and the hog's back could have been used. When using an ultrasonic vibrator on beef cattle, oil was not used and it was necessary to shave each animal at the locations where the fat measurements were to be taken (26, 27).

carcass measured twice) for 24 carcasses was only 0.0013. 6/ For these reasons, (objectivity, and consistency of results upon replication) the assumption that the carcass backfat measurements could be considered correct seemed warranted.

The Experienced Grader as an Estimator of Carcass Backfat Thickness

Correlation methods were not used in the analyses of the data of this study, except where needed to compare results with those of other studies.

In order that the grader of this study could be compared with others, the relationship between the grader's estimate for each hog and the actual average carcass backfat thickness from each hog was measured by correlation methods. As measured in this manner, the grader, when viewing the live animal, was able to discern 58 percent of the variation from hog to hog in average carcass backfat thickness. 7/

In a study reported in 1953, eye estimates of backfat thickness of live hogs at the seventh rib were correlated with carcass backfat thickness at that point (2). Three experienced swine judges, when viewing live animals, were able to discern from 18 to 27 percent of the variation from hog to hog in carcass backfat thickness at the seventh rib (as measured by correlation methods 8/). Two possible explanations of the low correlations are: (1) The judges in that study were estimating backfat thickness at a single point, which may be more difficult than estimating the average of backfat thickness measurements at several points. (2) That study was made several years ago, when graders had had less experience in estimating carcass backfat thickness.

6/ Similar variances for replications by the ultrasonic machine and by the grader on the same hogs were, respectively, 5 and 6 times larger. This indicates that the carcass measurement may be considerably more consistent (may more nearly give the same results when repeated on the same carcass) than is the ultrasonic machine or the grader on live hogs. In another study, a variance for replicate carcass measurements was practically the same as the 0.0013 (above) and as low for the average of 3 live probes upon replication (14). This is an indication that the probe may be more consistent than the ultrasonic device. The relative consistency of replicate measurements or estimates on a hog is unimportant from one viewpoint. That is, a method might be highly consistent with itself upon replication and be wrong both times. The purpose of this report is to compare the consistency of estimates by the grader and by the machine with actual carcass backfat thickness--not their consistency with themselves upon replication.

7/ The correlation coefficient was $\sqrt{.58} = 0.76$.

8/ The correlation coefficients ranged from $\sqrt{.18} = 0.42$ to $\sqrt{.27} = 0.52$.

In another study, the percentage of individual hogs placed in the correct grade, by live graders, averaged 54 percent for 16 experienced hog buyers operating on packer, dealer, and posted markets (21). The grader being compared with the ultrasonic device in this study placed 58.2 percent of the hogs in the correct grade.

On the basis of these comparisons the grader used in this study seemed to have above-average ability to estimate backfat thickness and to live-grade hogs.

The Grader Versus the Machine

Individual errors, rather than correlations, were used in the following analysis. For each hog, the grader's error was computed by subtracting his live estimate of average backfat thickness from the actual average carcass backfat thickness, measured at the three points. The ultrasonic machine's error was computed in the same way. An example of the computation of the two error figures for 10 of the hogs measured is given in table 2.

For each method, two features of the 170 errors are of particular significance: (1) The average size of the errors and (2) their variability from hog to hog. The average size of the errors shows how far the live estimates of the machine or grader were, on the average, from actual carcass backfat measurements. If one of the methods underestimates (or overestimates) backfat thickness fairly consistently, then the average error can be treated as a bias which may be allowed for by simply "adjusting the sights."

For each method, the variability of the individual errors about the average or mean error can be expressed as a standard deviation or as a variance. The variance is useful for statistical probability tests, but the standard deviation, the square root of the variance, is usually more meaningful (see Appendix C).

Individual Errors.--Individual errors for 10 of the hogs are shown in table 2. The errors (deviations of the estimate from the actual) could be considered by themselves if there were no consistent tendency for the errors to be biased. However, the average errors of both the grader and the machine were found to be significantly different from zero, and the standard deviations and variances were figured from the respective average errors (biases) of the two methods (table 2).

When variances unadjusted for bias were computed, the ultrasonic machine was still significantly more accurate than the grader in estimating carcass backfat thickness. Since the machine's bias was larger (average errors, table 2) than the grader's, allowing for bias further improved its relative accuracy rating.

Table 2.--Examples of computation of errors of the grader and the ultrasonic device in estimating carcass backfat thickness of 10 of the 170 hogs

Hog number	Average of three backfat thickness measurements on each carcass 1/	Grader's estimate of average	Average of three ultrasonic measurements	Grader's error 2/	Ultrasonic device's error 3/
	Inches	Inches	Inches	Inches	Inches
1	2.00	2.2	2.17	-0.20	-0.17
2	2.07	2.0	2.04	.07	.03
3	1.83	1.8	1.79	.03	.04
4	1.70	1.7	1.75	.00	-.05
5	1.67	1.7	1.63	-.03	.04
6	2.17	1.9	2.25	.27	-.08
7	1.53	1.6	1.58	-.07	-.05
8	1.87	1.7	1.75	.17	.12
9	1.57	1.8	1.46	-.23	.11
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
170	1.53	1.9	1.42	-.37	.11
Average error for the 170 hogs. 4/				-.05**(in.)	.10**(in.)
Standard deviation of the errors (from the mean error) 4/.				.21 (in.)	.14 (in.)
Variance of the errors (from the mean error)				.0423 5/	.0195 5/

**Significantly different from zero (at the .01 probability level.)

1/ These measurements are assumed to be without error.

2/ Average carcass backfat thickness, minus grader's estimate of same.

3/ Average carcass backfat thickness minus average of three ultrasonic measurements of backfat on the live hog.

4/ See Appendix C for interpretation of meaning of average errors and standard deviations of errors.

5/ Had the variance from zero error been used, rather than the variance from the mean error, the variance of the grader's error would have been about 5 percent larger than .0423 and similarly, the variance of the machine's errors would have been about 50 percent larger than .0195. The grader's error variance, however, would still have been significantly larger than that of the machine's.

Average Errors.--Since the average errors have proven to be significantly greater than zero, (table 2) they were considered to be consistent enough to be relied upon and considered as biases for which adjustments could be made.

For the 170 hogs, the grader's average error, in which individual overestimates were partially compensated for by underestimates, was an overestimate of about .05 inch or 1/6 of a grade step in backfat thickness (a grade step is .3 inch--table 5). The machine underestimated the actual average carcass backfat thickness of each hog by an average of .1 inch (1/3 of a grade step). Having seen what his bias was, the grader may be able to avoid it or compensate for it in future work. Whether or not a .1-inch error is a natural bias for an ultrasonic device can be determined by further tests of the machine. 9/

9/ Several explanations of the apparent bias in the estimates are possible. Although it may be that the grader had a tendency to overestimate, it is also possible that he was accustomed to hogs of a different type than some or all of the 170 hogs of this study.

The underestimation of backfat thickness by the ultrasonic machine may have been due to compression of the fat. The operator found it necessary to apply some pressure, as he held the vibrator against the hog's back, in order to express air bubbles from the oiled hair and to compress the hair thickness to a minimum. Several other explanations for the machine's underestimating are possible, including the possibility that the rate of travel of ultrasonic sound waves through live pork fat was underestimated in calibrating the oscilloscope. Another contributor could be the posture difference between the standing animal and the hanging carcass.

Individual Errors as Measured from the Average Error.--The standard deviations (table 2) are the number of inches above and below the average errors of the indicated method within which 2/3 of the individual errors tended to fall. Appendix C interprets the meaning of the average errors and standard deviations of errors. The grader estimated about 2/3 of the hogs with an error of .21 inches or smaller from his average error (standard deviation of the errors = 0.21 inch). The machine measurements were able to place about 2/3 of the hogs within .14 inch or less error from the average error of the machine (standard deviation of errors = 0.14 inch, table 2). The variance (standard deviation squared) of the grader's errors was more than twice that of the machine, and the difference between their respective variances, .0423 and .0195, was highly significant. 10/

Even though the grader made a smaller average error (had less bias) than the machine, his individual errors were usually larger. The ultrasonic measurements were more precise as estimators of average carcass backfat thickness than were the estimates of the experienced grader employed in this study.

Although there may be graders who can make closer estimates of backfat thickness than the experienced grader employed in this study, there are also good graders who cannot do as well. The operation of the machine requires less judgment ability than a grader needs. The machine's performance can be expected to be uniformly good with any properly trained operator, while the accuracy with which individual graders could estimate backfat thickness would vary considerably (21).

10/ The "F" ratio of the two variances (.0423/.0195) was 2.17 which indicates that the probability of their being from two methods tending to produce errors of the same size is considerably less than one in a hundred. Were it appropriate to compute variances around zero error rather than around the average error, they would also be highly significantly different in a probability sense. That is, even without allowing for bias--and the machine had more bias--the machine was significantly more precise than the grader in estimating carcass backfat thickness.

It was mentioned earlier that the correlation between the grader's estimate and the average carcass backfat thickness was .76 for the 170 hogs. The correlation between the average backfat thickness obtained by the ultrasonic machine and from the carcasses was .89. This also indicates that the machine was a more accurate estimator of average carcass backfat thickness than was the grader. An even higher correlation would be expected for the machine had the spots at which ultrasonic measurements were made been marked on the live hogs, and carcasses measured at exactly the same points.

Accuracy in Estimating Carcass Backfat Thickness Classes.--A grading method is generally more accurate when estimating the number of hogs in each class or grade than when estimating the class or grade of each hog individually. For each hog misplaced from grade 1 to grade 2 opposite misplacings can offset such incorrect placings in estimating the number of hogs in each grade.

Table 3 presents the accuracy of the grader and of the ultrasonic device in estimating the carcass backfat thickness types into which the live hogs were to fall when butchered. Backfat thickness type No. 1 would represent a carcass meeting the standards for U. S. No. 1 considering backfat thickness alone. See table 8.

Table 3 presents the accuracy of the grader and of the ultrasonic device in the two ways, where the standard of accuracy is the backfat thickness of the carcass. As the table shows, there was, in this study, an increase in individual grading or classing accuracy of more than 10 percentage points (55.9 to 67.6 percent) or over 20 percent, as individual hogs were classed into backfat thickness types by the grader and then by the ultrasonic device.

Table 3.--Accuracy in estimating backfat thickness types of 170 individual hogs and the accuracy of estimating number of hogs in each backfat thickness type using type estimates of individual hogs

Method	Percentage of hogs classed correctly 1/	Accuracy of estimation of number of hogs in each type 2/ 3/
	Percent	Percent
Live estimates of backfat by grader	55.9	61.8
Live estimates of backfat by ultrasonic device	67.6	84.9

1/ The total number of hogs placed correctly, divided by the total number of hogs and expressed as a percentage.

2/ Where incorrect placings = I. I = (for each type) the grader or the grading method's estimate of the number in this type or class, using type estimates of each individual hog, minus the number actually in that type. The indicated percentage is then the total number of hogs, minus the sum of the I's for each type, divided by the total number of hogs.

3/ The percentages in this column, when multiplied by the value differentials for perfect sorting (table 6) yield approximately the value differentials computed for the two grading methods in table 6.

If large numbers of hogs are to be marketed at one time by one producer and records of grades of individual animals is not needed, the accuracy of estimation of number of hogs in each type (table 3) may be a sufficient criterion of grading accuracy. This accuracy was increased 23.1 percentage points from 61.8 to 84.9 percent or more than 37 percent.

RELATIONSHIP OF CARCASS VALUE TO BACKFAT THICKNESS AND LOIN EYE AREA, AND POSSIBLE APPLICATIONS OF THE ULTRASONIC DEVICE

This report has shown that, at least in one situation, an ultrasonic device was more accurate than a grader in classifying live hogs according to backfat thickness. 11/ It follows that the ultrasonic device could have added to the grader's ability to classify hogs into carcass grades by giving him closer estimates of backfat thickness than he could make unaided.

Backfat Thickness and Carcass Value

Many studies have been made of various indicators of carcass value. Of indicators available on the unbroken half-carcass, backfat thickness is the most accurate yet found. Given carcass weight or length, backfat thickness is highly correlated with the proportional yield of high-value lean cuts from a carcass. A number of the studies were conducted in the North Central Region in the late 1940's and early 1950's, (4, 7, 12, 25, 32). Results varied slightly with variations in types of hogs, cutting methods, animal weights, etc. Table 4 shows, for each study, the number of hogs measured, the average within-weight-group correlation between average backfat thickness and percent lean cuts, and the respective correlation coefficients, squared. The square of a correlation coefficient indicates the proportion of the variation in percent lean cuts associated with variation in backfat thickness.

Figure 4 (from data in 7) illustrates the relationship between carcass backfat thickness and the yields of various carcass products. Data, largely from that study, have been used by the U. S. Department of Agriculture in the development of standards for grades of pork carcasses. The standards, first adopted as official in 1952, were revised slightly in 1955 (28). Official standards for grades of live hogs have also been promulgated by the Department (29). The live hog grade standards provide guides to the grader for estimating the carcass grade to result after the hog is slaughtered.

11/ Evidence that leaner, faster-growing animals can be selected by the live probe and the Leanmeter suggests that the ultrasonic device might also be useful in selecting breeding stock for swine improvement. However, unless it can be made to estimate muscling directly, the device may not be more useful than methods presently available. A British announcement states that the ultrasonic device is useful in selecting boars and concludes that the ultrasonic technique is simple, humane, and accurate (3). Another European report describes possible use of the device in swine testing, and states that it is sufficiently accurate for that work (9).

Table 4.--Relationship between average carcass backfat thickness and percent lean cuts -- averages for carcasses within 10-pound weight groups

Study	Number of hogs	Average Correlation	Square of correlation
Indiana	701	0.841	70.8
Iowa	600	.895	80.1
Michigan	298	.688	47.4
Minnesota	695	.864	74.6
Missouri	592	.838	70.2
Ohio	374	.756	57.2
Region	3,260	.840	70.5

Source (22).

Grades of hog carcasses are based largely on backfat thickness. The U. S. No. 1 carcass has the minimum fatness required to produce high-quality pork cuts. No. 2 carcasses are slightly fatter than necessary and No. 3 carcasses are decidedly overfat. Medium carcasses are too thin, and Cull carcasses are decidedly too thin, to yield top-quality pork cuts. The official weight and measurement guides for grades of barrow and gilt carcasses are given in table 5.

Loin Eye Area and Carcass Value

Loin eye muscle area is another good indicator of the percentage of high-value lean cuts in a hog carcass. Knowledge of this measure, in addition to knowledge of backfat thickness, adds significantly to the correlation between the estimated and the actual percentage of lean cuts in a carcass (19, 23, 33). Since loin eye area cannot be measured by traditional methods without damaging the wholesale loin, its measurement is not included in the grade specifications. However, ultrasonic estimation of loin eye muscle area may eventually be possible, using the diameter of the muscle (31).

Speed of Application of the Ultrasonic Device

In this test it was possible to measure the live hogs, at the three sites along the center of the back (ham, middle, and shoulder) more rapidly than one per minute. Development of special facilities for handling the hogs could increase this rate.

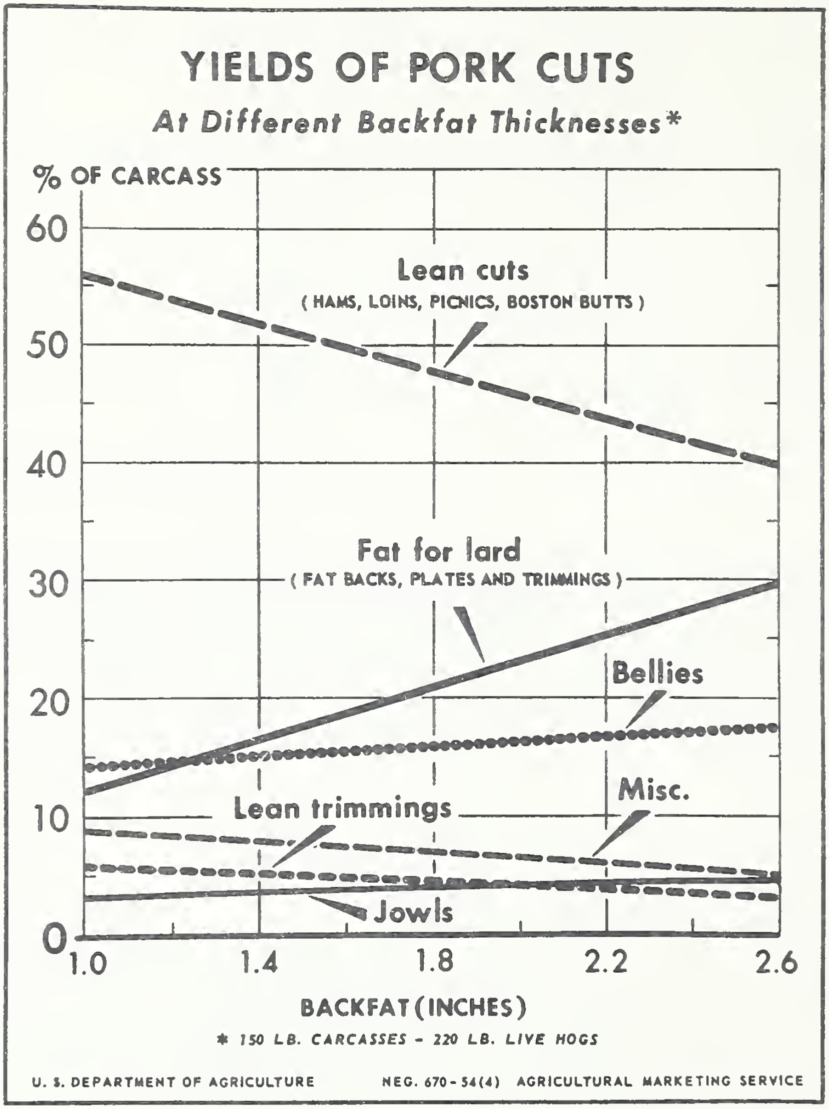

Figure 4

Appendix A explores the possibility that the application of the ultrasonic device could be speeded by taking one measurement per hog rather than three. In this study, the ultrasonic measurement at the ham site alone was nearly as closely associated with average carcass backfat thickness as was the average per hog of the three ultrasonic measurements. However, studies using the live probe and Leanmeter have obtained better association at other sites than at the ham site. Therefore, measurement at one site to speed application is not recommended without further study.

Table 5.--Weight and measurement guides to grades for barrow and gilt carcasses

Carcass weight or length 1/	Average backfat thickness by grade 2/				
	U. S. No. 1	U. S. No. 2	U. S. No. 3	Medium	Cull
	Inches	Inches	Inches	Inches	Inches
Under 120 pounds or under 27 inches	1.2 to 1.5	1.5 to 1.8	1.8 or more	0.9 to 1.2	Less than 0.9
120 to 164 pounds or 27 to 29.9 inches	1.3 to 1.6	1.6 to 1.9	1.9 or more	1.0 to 1.3	Less than 1.0
165 to 209 pounds or 30 to 32.9 inches	1.4 to 1.7	1.7 to 2.0	2.0 or more	1.1 to 1.4	Less than 1.1
210 or more pounds or 33 or more inches	1.5 to 1.8	1.8 to 2.1	2.1 or more	1.2 to 1.5	Less than 1.2

1/ Either carcass weight or length may be used with backfat thickness as a reliable guide to grade. The table shows the normal length range for given weights. In extreme cases where the use of length with backfat thickness indicates a different grade than by using weight, final grade is determined subjectively as provided in the standards. Carcass weight is based on a chilled, packer style carcass. Carcass length is measured from the forward point of the aitch bone to the forward edge of the first rib.

2/ Average of measurements made opposite the first and last ribs and last lumbar vertebra.

Grading Accuracy and Value Differentials Between Grades

Wider price differentials between grades of hogs would contribute to progress in swine improvement by strengthening the incentive for production of higher quality.

Data from a hypothetical example in Appendix B illustrate how an increase in grading accuracy could result in wider price differentials between grades of hogs. A standard deviation of error of zero was considered to represent perfect grading accuracy and an increase in the standard deviation to indicate a decrease in grading accuracy. In the example, 1957 wholesale prices and typical average carcass and cut yields were used for hogs of 13 carcass backfat thickness classes. Carcass backfat thickness was used as the sole criterion of per-hundredweight value.

A decrease in the error of estimating or forecasting average carcass backfat thickness from a standard deviation of error of 0.21 inch (accuracy of the grader) to one of 0.14 inch (accuracy of the ultrasonic device) was used in the example. In the example, as grading accuracy improved from "no ability to grade" to the "accuracy of the grader," the value differential between hogs having U. S. No. 1 backfat thickness (U. S. No. 1 type) and those having backfat thickness of U. S. No. 2 hogs (U. S. No. 2 type) increased from zero to 21 cents per live hundredweight (table 6). The differential between U. S. No. 2 type hogs and U. S. No. 3 type hogs increased from zero to 31 cents (table 6). In the example, the respective grade-price differentials were 27 and 38 cents when the hypothetical hogs were graded with the accuracy of the ultrasonic device, or 6 and 7 cents greater than when the hogs were graded with the accuracy of the grader.

If grading accuracy had been perfect (zero standard deviation of error) the respective between-grade value differentials in the example would have been increased an additional 9 and 6 cents to 36 and 44 cents (table 6).

Although the example uses the grading performances of a grader and an ultrasonic device, it illustrates the principle that increased grading accuracy, by whatever means brought about, makes wider price differentials possible.

Table 6.--Value differences between types of hogs as classified by different grading methods

Grading method	Value differentials, per live hundredweight, between hogs of indicated backfat thickness type	
	U. S. No. 1 type minus U. S. No. 2 type values 1/	U. S. No. 2 type minus U. S. No. 3 type values
	Cents	Cents
No ability to grade	00	00
Standard deviation of error of .21 inch (accuracy of the grader)	21	31
Standard deviation of error of .14 inch (accuracy of the ultrasonic device) ...	27	38
Standard deviation of error of 0.0 inch (perfect grading accuracy) 2/......	36	44

1/ U. S. No. 1 type hogs are hogs meeting U. S. No. 1 backfat thickness requirements regardless of their other quality characteristics.

2/ The value differentials for perfect sorting, when multiplied by the percentage grading accuracies in the second column of table 3, yield approximately the value differentials of this table for the grader and the ultrasonic device.

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APPENDIX A

Ultrasonic Measurements at Individual Sites as Estimators of Average Carcass Backfat Thickness

Application of the ultrasonic device to three sites on a hog may be too time consuming for economical use in grading live slaughter swine. Therefore, the ultrasonic measurement at each site was compared with the average of the three carcass backfat measurements.

Table 7 indicates that the error variance of the grader's estimate of average backfat thickness on a hog was enough larger than the error variance of the ultrasonic measurement at the ham site for the difference to be highly significant in a statistical or probability sense. In addition, the variance of the error of the ultrasonic measurement at the ham (.0241) was not significantly larger than the variance of the error of the average of the three ultrasonic measurements (.0195).

These comparisons would suggest that ultrasonic measurement at the ham site alone might prove to be nearly as useful as the average of three ultrasonic measurements -- and a little quicker to obtain. However, some tests have found other sites to be better places to measure (1, 11, 15). A test with the Leanmeter found the middle site to be better than the ham site. A test with the probe found a location immediately behind the shoulder to be best. The shoulder site gave poorest results with the ultrasonic device. This may be explained (1) by an irregularity in backfat thickness located directly over the shoulder, which makes it difficult to obtain consistent results at that site, and (2) by a layer of "false" lean embedded in the backfat at that point.

The probe and the Leanmeter are generally applied an inch or two off the midline while, in this study, the ultrasonic device was applied directly over the backbone. Data from other studies indicate that even for carcass measurements, the average of three backfat measurements provides significantly better estimates of carcass value than any one alone.

Wholesale cutout values were not obtained from the hogs in this study, so it was not possible to relate ultrasonic measurements at the various sites to carcass values.

Table 7.--Average errors and comparison of variances of errors of various estimators of average carcass backfat thickness

Estimate or measurement 1/	Average error	Variance of error	Significance of difference from ultrasonic ham site error 2/	Significance of difference from error of average of 3 sites
	Inches			
Grader estimate of back-fat thickness	-0.05	.0423	**	**
Average of 3 ultrasonic measurements	.10	.0195	N.S.	--
Ultrasonic measurements at shoulder	-.26	.0509	**	**
Ultrasonic measurements at middle of back	.33	.0331	*	**
Ultrasonic measurements at ham	.23	.0241	--	N.S.

1/ Estimate or measurement that was subtracted from average carcass backfat thickness. Ultrasonic measurements were taken over the center of the backbone.

2/ ** Significantly different at the .01 probability level.
* Significantly different at the .05 probability level.
N.S. Not significantly different at the .05 probability level.

APPENDIX B

Wider Value Differentials Between Grades Through Improved Grading Accuracy

The purpose of this appendix is to demonstrate, with an example, that improved grading accuracy would result in wider value differentials between grades of hogs. Larger value differentials would permit packers to pay larger price differentials which, in turn, would provide additional encouragement for farmers to improve their hogs.

Data for the Example

The standard deviation of the errors of the grader in estimating backfat thickness was .21 inch (hereafter called grading method "A" to emphasize the fact that the purpose of this appendix is to illustrate a principle that does not depend on the grading methods involved). The standard deviation for the errors of the ultrasonic device was .14 inch (grading method B in this example). The hogs in the following example are to be placed in grade types by method "A" and also by method "B" and purchased by the packer at prices which reflect the values of the groups into which the grading method used places them. The live grade type into which a hog will be placed will depend upon the backfat thickness estimate made by the grading method employed, regardless of whether the estimate is correct and regardless of indicators of quality other than apparent backfat thickness.

Actual carcass backfat thicknesses of the carcasses of the 170 hogs that were measured in the test of the ultrasonic device were distributed as shown in table 8. 12/ The hogs coming to market in the hypothetical example to be presented are assumed to have the same distribution. For example, 7 percent of the hogs in the example will be assumed to meet the carcass backfat requirements of the thinner third of U. S. No. 1 grade and will be called U. S. No. 1 type along with the other hogs meeting U. S. No. 1 backfat requirements (table 8).

Since the wholesale cuts of the hogs were not weighed, the exact value of each carcass is not available. The third column in table 8 indicates the average value that the example assumes for hogs of each carcass backfat thickness. The liveweight value per hundred pounds of the U. S. No. 1 hog in (8) was $19.84; the No. 2 hog, $19.44; the No. 3 hog, $19.04. Typical carcass and cut yields and Chicago wholesale prices of cuts for 1957 were used to obtain the values. The assignment of values to hogs of Medium type (Medium backfat thickness) in table 8 was arbitrary but represented the best judgment

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12/ Table 8 collects the continuous distribution of backfat thicknesses to the nearest .05 inch, resulting in 13 discrete groupings.

Table 8.--Percentage distribution by type of hog measured, and assumed value per live hundredweight

Type (grade considering only average carcass backfat thickness of each animal)	Percentage of hogs falling within each type 1/	Assumed average value per live hundredweight of hogs of the indicated backfat thickness type
	Percent	Dollars
Medium		
1.05 inches backfat ...	1	19.30
1.15 inches backfat ...	4	19.44
1.25 inches backfat ...	4	19.57
Average (weighted)...		19.48
U. S. No. 1		
1.35 inches backfat ...	7	19.98
1.45 inches backfat ...	11	19.84
1.55 inches backfat ...	11	19.71
Average (weighted)...		19.82
U. S. No. 2		
1.65 inches backfat ...	16	19.58
1.75 inches backfat ...	13	19.44
1.85 inches backfat ...	10	19.30
Average (weighted)...		19.46
U. S. No. 3		
1.95 inches backfat ...	9	19.17
2.05 inches backfat ...	6	19.04
2.15 inches backfat ...	5	18.90
2.25 inches backfat ...	3	18.76
Average (weighted)...		19.02

1/ Except for a few extremely fat and extremely thin animals, this is the distribution of the animals measured in the study of the ultrasonic device; backfat thickness of each animal, is rounded to the nearest .05 inch to facilitate computation of the example.

of the author. The values just mentioned for the middle of grades 1, 2, and 3 are 40 cents apart. With each type broken into three backfat thickness groups in this example, values 13 or 14 cents apart were inserted to fill gaps in the third column of table 8.

Both grading methods A and B are less than perfect. In the example, some of the No. 1 type hogs will, of course, be misclassed as U. S. No. 2 type. The hogs that are misclassed in this direction will tend to increase the true average value of the hogs classed as No. 2 by the grading method being used. Likewise, opposite misplacings will lower the true value of hogs classed as No. 1 type by incorrectly placing some No. 2 type hogs in with the No. 1 type. At the same time, misplacings between types 2 and 3 will tend to lower the value of hogs classed as type 2 and raise the value of hogs classed as type 3. True value refers to the actual carcass values assumed in table 8. The greater the grading accuracy, the nearer the average values of the hogs classed into each grade type will be to those of table 8.

Since values assigned to the Medium-type hogs were arbitrary, average values of the grade types into which the hogs were classified by the two grading methods are also computed ignoring the Medium-type hogs and the hogs that were misclassed as Medium-type by methods "A" and "B."

The example of this appendix does not use indicators of value other than backfat thickness, because backfat thickness was the only ultrasonic measurement attempted on the 170 hogs of this report. The official backfat thickness standards for 120-to-164-pound carcasses were used (170-to-235-pound live hogs, approximately--table 5).

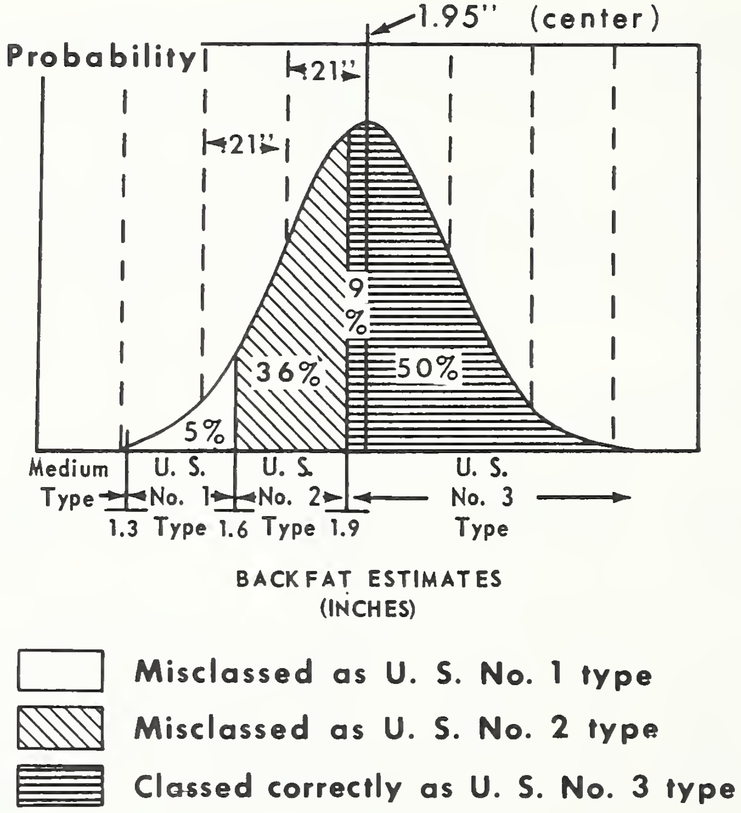
Computation of the Example

The remainder of this appendix explains how the value differentials of table 6 were computed. Figure 5 uses the hogs with 1.95 inches carcass backfat thickness to illustrate the method.

The height of the normal curve, figure 5, from its base at any point indicates the relative frequency of occurrence (probability) of the various backfat estimates that would be expected using method "A" on hogs of 1.95 inches backfat. One-half of the area under a normal curve lies on each side of the center, where the curve peaks. The normal curve in figure 5 is centered at 1.95 inches, meaning that the grading method will estimate 1.95 inches, the correct backfat thickness, more frequently than it will yield any other specific estimate. Method "A" will yield an estimate of 1.3 inches or lower only very seldom for hogs actually having 1.95 inches of backfat.

This example illustrates what happens near a grade boundary. The 1.95 inch backfat hogs are U. S. No. 3 type but are only .05 inch from the U. S. 2-3 type borderline of 1.90 inches, so the relative frequency of misgrading as U. S. 2 type is quite high. This distance (.05 inch) was converted into standard deviations. That is, .05 inch, the distance to the grade boundary, is .05/.21 or .238 standard deviations for method "A." Therefore, 1.95 inches is .238 standard deviations from the grade boundary of 1.90 inches. Further, it is (1.95-1.60)/.21 = 1.67 standard deviations from the U. S. 1-2 type boundary of 1.6 inches.

EXAMPLE OF DISTRIBUTION OF ERRORS OF ESTIMATES OF BACKFAT THICKNESS FOR HOGS HAVING 1.95 INCHES BACKFAT THICKNESS*



*EXAMPLE FOR GRADING OF HOGS HAVING AVERAGE CARCASS BACKFAT THICKNESS OF 1.95 INCHES; BY A GRADER HAVING A STANDARD DEVIATION OF ERROR OF ESTIMATING BACKFAT THICKNESS OF .21 INCHES.

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Figure 5

A table showing areas of a standard normal curve would indicate that about 36 percent of the area of the standard normal curve of figure 5 would lie between the boundaries on either side of type 2 (distances of .238 to 1.67 standard deviations to the left of the center). 13/ Five percent would lie to the left of the boundary between types 1 and 2 (1.67 standard deviations to the left of the center). This means that one would expect 36 percent of the 1.95-inch-backfat hogs to be misgraded as U. S. No. 2 type, and 5 percent misgraded as far as U. S. No. 1 type (estimates of less than 1.6 inches) and practically none to be misgraded as far as Medium.

None of the 50 percent of the hogs on which backfat thickness was overestimated was a source of misgrading in this particular example because grade 3 has no upper limit on backfat thickness. The 9 percent of the area immediately to the left of the center in figure 5 represents 9 percent of the 1.95-inch-backfat hogs for which method "A" would underestimate backfat thickness, but not by enough to misgrade the hogs. This leaves 59 percent in the correct type classification.

All hogs in figure 5 have 1.95 inches average carcass backfat thickness, and these hypothetical hogs have an average live hundredweight value of $19.17. The 5 percent of the 1.95-inch hogs that grading method "A" misgraded as U. S. No. 1 type helped pull down the average value of the No. 1 type hogs as classified by method "A." This, and similar misgradings of hogs of other backfat thicknesses, accounted for the fact that the value differences between grade types (table 6) are smaller for that method than for the more precise method "B."

Method "B" would have misclassed a smaller proportion of the hogs. When the procedure of figure 5 was performed for method "B" on the 1.95-inch hogs, only 1 percent were misclassed as U. S. No. 1 type and 35 percent misclassed as U. S. No. 2 type. Fourteen percent (rather than 9) were underestimated, but not by enough to place them in the wrong type.

The procedure of figure 5 was performed for both grading methods for each of the 13 backfat thickness types and the results are tabulated in tables 9 and 10 after adjustment for the number of hogs in each backfat thickness type. Nine percent of the hogs had 1.95 inches average backfat thickness (table 8) and of these hogs, 5 percent were classified (mistakenly) by method "A" as being within the U. S. No. 1 backfat thickness range (figure 5). Thus, 5 percent of 9 percent gives the .45 percent listed in table 9 under U. S. No. 1 after the backfat thickness of 1.95 inches.

13/ Tables of areas of standard normal distributions for various portions of a standard deviation are presented in different ways. A table which presents the area in one tail of the distribution is the most convenient for the example above. Since it is not clear in some texts what area is being referred to, the bibliography lists two texts in which the type of table is clearly indicated and is the most convenient for the use above (5, 30).

Table 9.--Classification of hogs by grading method "A" (larger error)

Carcass backfat thickness and average live hundredweight value of grade type	Live grade types into which hogs were classified				
	Medium	U. S. No. 1	U. S. No. 2	U. S. No. 3	Total
	Percent	Percent	Percent	Percent	Percent
Medium type					
1.05" ($19.30)	[1]0.88	0.12	--	--	1.00
1.15" ($19.44)	[1]3.04	.88	0.08	--	4.00
1.25" ($19.57)	[1]2.16	1.64	.20	--	4.00
U. S. No. 1 type					
1.35" ($19.98)	2.87	[1]3.29	.84	--	7.00
1.45" ($19.84)	2.64	[1]5.72	2.42	0.22	11.00
1.55" ($19.71)	1.32	[1]5.17	3.96	.55	11.00
U. S. No. 2 type					
1.65" ($19.58)	.80	5.76	[1]7.52	1.92	16.00
1.75" ($19.44)	.26	2.86	[1]6.76	3.12	13.00
1.85" ($19.30)	--	1.20	[1]4.70	4.10	10.00
U. S. No. 3 type					
1.95" ($19.17)	--	.45	3.24	[1]5.31	9.00
2.05" ($19.04)	--	.12	1.32	[1]4.56	6.00
2.15" ($18.90)	--	--	.60	[1]4.40	5.00
2.25" ($18.76)	--	--	.15	[1]2.85	3.00
Total	13.97	27.21	31.79	27.03	100.00
Average live hundredweight value of hogs classified into grade types by method "A"	$19.67	$19.66	$19.47	$19.16	
Between-grade-type value differentials		$.01	$.19	$.31	
Value and differential figures had Medium-type hogs and other hogs misclassed as Medium (boxed-in figures) not been included in example					
Average live hundredweight value, hogs classified into grade types by method "A"		$19.68	$19.47	$19.16	
Between-grade-type value differentials			$.21	$.31	

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[1] Classified correctly. Percentages to the left represent underestimation of backfat thickness sufficient for misclassing. Percentages to the right represent overestimation of backfat sufficient for misclassing.

Table 10.--Classification of hogs by grading method "B" (smaller error)

Carcass backfat thickness and average live hundredweight value of grade type	Live grade types into which hogs were classified				
	Medium	U. S. No. 1	U. S. No. 2	U. S. No. 3	Total
	Percent	Percent	Percent	Percent	Percent
Medium type					
1.05" ($19.30)	1/1.96	0.04	--	--	1.00
1.15" ($19.44)	1/3.44	.56	--	--	4.00
1.25" ($19.57)	1/2.56	1.40	0.04	--	4.00
U. S. No. 1 type					
1.35" ($19.98)	2.52	1/4.20	.28	--	7.00
1.45" ($19.84)	1.54	1/7.92	1.54	--	11.00
1.55" ($19.71)	.44	1/6.60	3.85	0.11	11.00
U. S. No. 2 type					
1.65" ($19.58)	.16	5.60	1/9.60	.64	16.00
1.75" ($19.44)	--	1.82	1/9.36	1.82	13.00
1.85: ($19.30)	--	.40	1/6.00	3.60	10.00
U. S. No. 3 type					
1.95" ($19.17)	--	.09	3.15	1/5.76	9.00
2.05" ($19.04)	--	--	.84	1/5.16	6.00
2.15" ($18.90)	--	--	.20	1/4.80	5.00
2.25" ($18.76)	--	--	.03	1/2.97	3.00
Total	11.62	28.63	34.89	24.86	100.00
Average live hundredweight value of hogs classified into grade types by method "B"	$19.64	$19.72	$19.47	$19.09	
Between-grade-type value differentials		-$.08	$.25	$.38	
Value differential figures had Medium-type hogs and other hogs misclassed as Medium (boxed-in figures) not been included in example					
Average live hundredweight value of hogs classified into grade types by method "B"		$19.74	$19.47	$19.09	
Between-grade-type value differentials			$.27	$.38	

1/ Classified correctly. Percentages to the left represent underestimation of backfat thickness sufficient for misclassing. Percentages to the right represent overestimation of backfat sufficient for misclassing.

Results, Ignoring Medium Type.--The lower sections of tables 9 and 10 present the average values of the hogs classified into the indicated grade types, with Medium-type hogs and hogs misclassed as Medium-type ignored. The value differentials which have already been presented in table 6, are from the lower sections of tables 9 and 10. The average live hundredweight value of each grade type into which the hypothetical hogs were classified (tables 9 and 10) was computed by (1) summing the products of the individual type values in the first column and the corresponding percentages in the grade-type column in question , and (2) dividing that sum by the total percentage of all hogs that were placed in that grade type. Of all the hogs in the example, method "A" placed 27.21 percent in the U. S. No. 1 type (table 9).

Ignoring Medium-type hogs misclassed as U. S. 1 requires not using the first three rows of the tables and for table 9, subtracting 0.12, 0.88, and 1.64 percent from the 27.21 percent.

Results, Considering Medium Type.--Medium-type hogs, as classed by method "A," were worth more, in this example, than the U. S. No. 1 type hogs. This can be explained by referring to the total percentages in each grade class. There are relatively few Medium-type hogs, compared to the number of U. S. No. 1 type. Therefore, the high-value U. S. No. 1 type hogs that would be misgraded as Medium type, because of backfat estimation errors, would sharply raise the actual value of the hogs that method "A" classes as Medium type. At the same time, quite a number of U. S. 2-type hogs would be misgraded as U. S. No. 1 type, lowering the actual value of the hogs classed as U. S. No. 1 type.

APPENDIX C

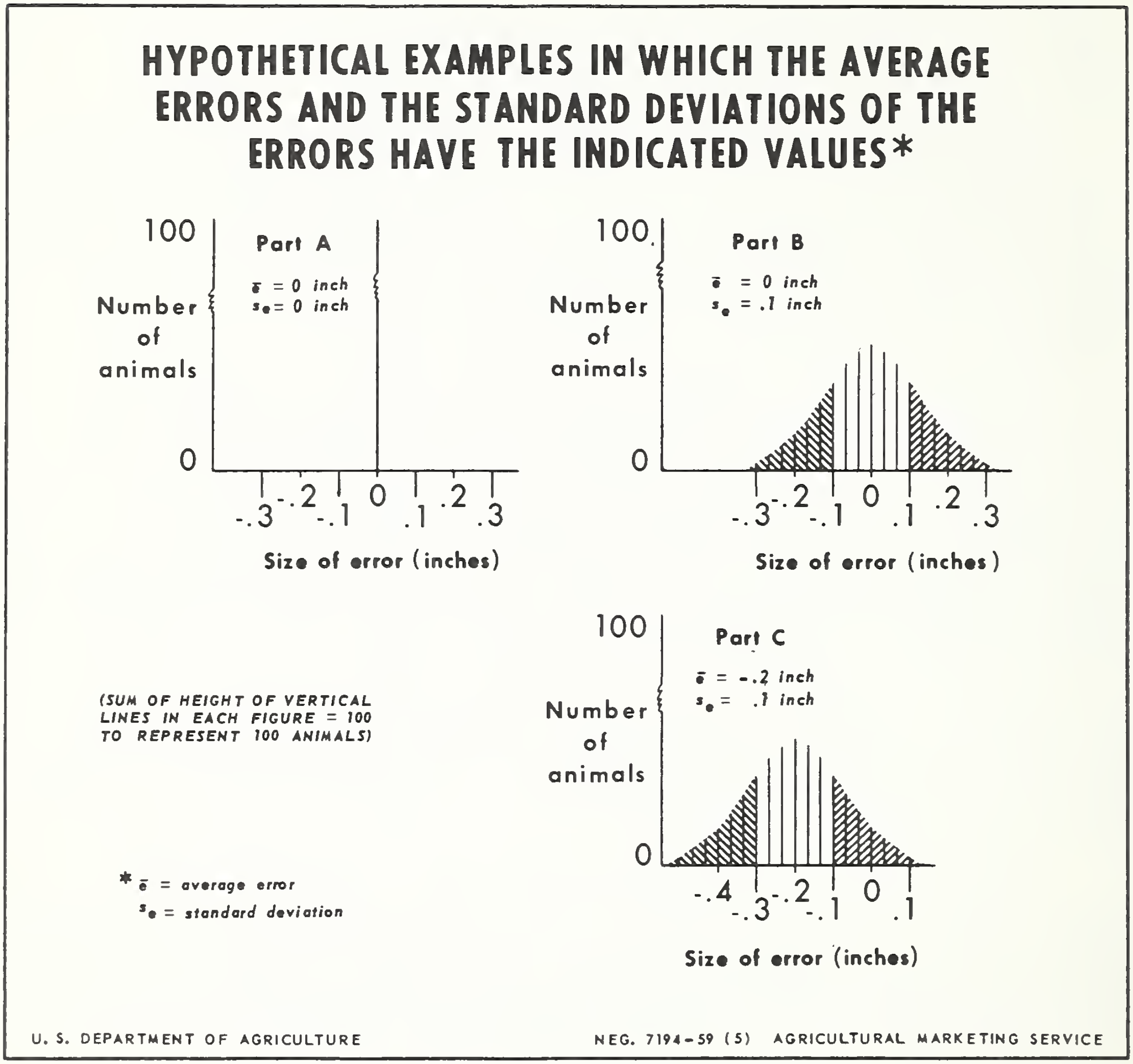
Interpretation of Meaning of Average Errors and Standard Deviations of Errors

Some hypothetical examples may help illustrate the meaning of average error and of standard deviation of individual errors about the average error such as those shown in table 2. Part A of figure 6 illustrates a hypothetical example in which both the average error and the standard deviation, measured about the average error, are zero. That is, assuming the machine's accuracy were being tested, the machine would have estimated backfat thickness correctly on each of the 100 animals in this illustration.

In the hypothetical example illustrated in part B of figure 6, the average of the errors for the 100 hogs was zero and the standard deviation was 0.1 inch. (It is assumed that grading errors of each method are distributed in a normal fashion about the mean error for the method in question. In a normal distribution, a distance of one standard deviation in each direction from the mean includes about 2/3 of the total number of observations--errors, in this case.) Therefore, on the average, the machine in part B of figure 6 estimated correctly (zero average error) but about 1/3 of the time the machine was 0.1 inch or more off--either too high or too low. That is, 1/3 of the time the error would be large enough to be in one of the shaded areas of part B.

If, as in the hypothetical example illustrated in part C of figure 6, the average error had been -0.2 inch and the standard deviation of the errors had been 0.1 inch; then, on the average, the machine would have overestimated by 0.2 inch. The standard deviation of 0.1 inch indicates that 1/3 of the errors would be 0.1 inch or more above or below the -0.2 inch average error.

The hypothetical performance of the machine, illustrated in part C of figure 6 where there was a -0.2 inch average error is not necessarily poorer than the hypothetical performance of the machine in part B where the average error was zero. The standard deviation of the errors was the same in part B and part C of figure 6. The average error, or bias, of part C could be taken into account and reduced to zero by "adjusting the sights" to allow for it.



HYPOTHETICAL EXAMPLES IN WHICH THE AVERAGE ERRORS AND THE STANDARD DEVIATIONS OF THE ERRORS HAVE THE INDICATED VALUES*

(SUM OF HEIGHT OF VERTICAL LINES IN EACH FIGURE = 100 TO REPRESENT 100 ANIMALS)

* $\bar{e}$ = average error
s_e = standard deviation

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Figure 6